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Title: Resonant ultrasound spectroscopy for anisotropic materials with misaligned geometric and material axes.

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Los Alamos
NATIONAL LABORATORY

Resonant ultrasound spectroscopy for anisotropic materials with misaligned geometric and material axes.

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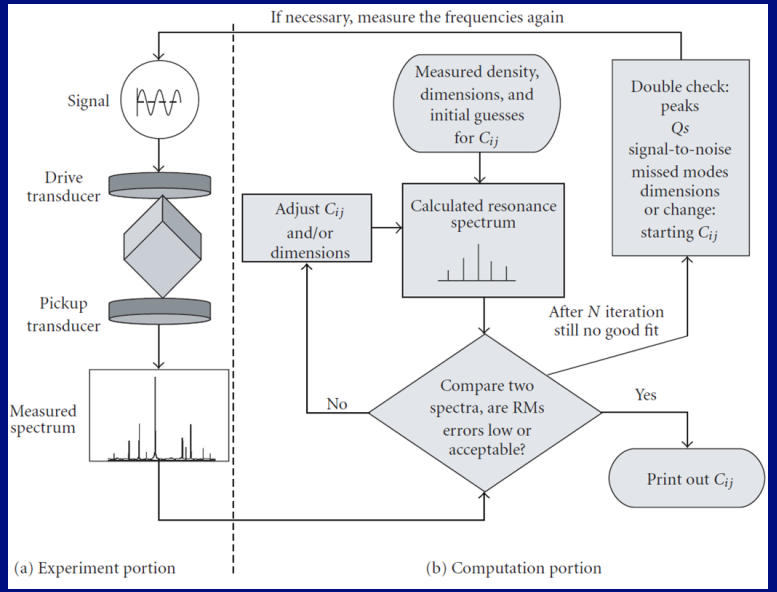
Agenda

1. Standard method RUS inversion
2. FEM based RUS inversion method
3. Advanced RUS inversion method with Euler angles
4. Conclusion and future work

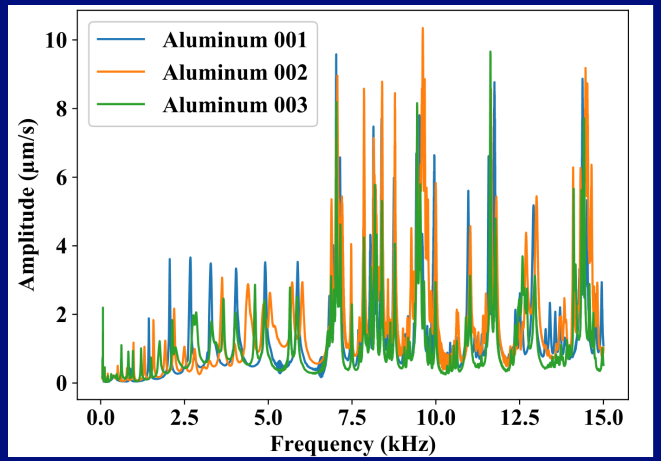
Standard RUS Inversion

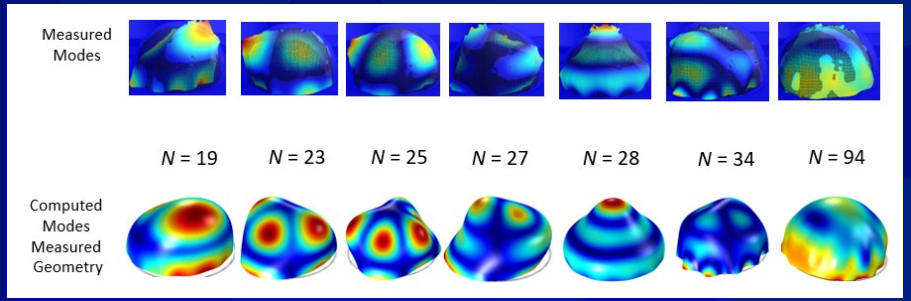
- Constrained to parts of simple geometries
- Fast forward modeling i.e. Raleigh Ritz
- Several modes needed
- Limited to relatively simple materials



Finite Element Method (FEM) RUS Inversion

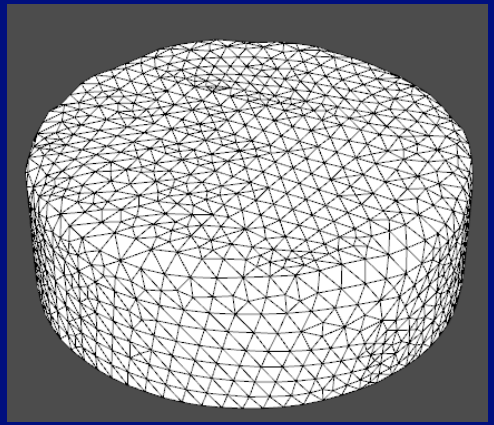
- Arbitrary shapes
- As built geometries (CMM Scan)
- Complex material properties with misaligned material axes.
- Mode shape matching



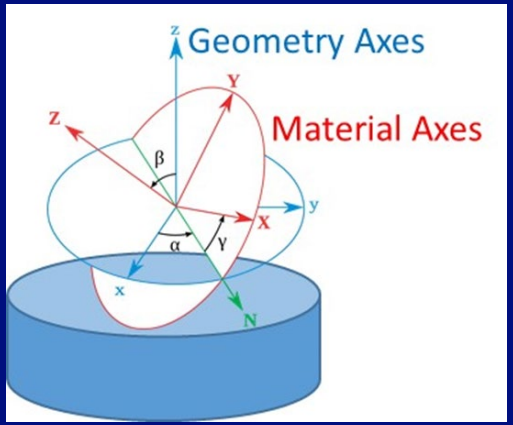


Advanced RUS Inversion Method with Euler angles

- Euler angle rotation (Z-X-Z)
- Off axis rotation due to majority alignment of granular material
- Global material rotation
- Large effect to mode shape
- Pressed Idoxuridine (IDOX)

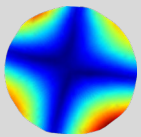
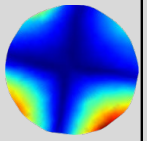
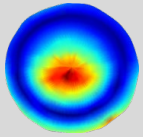
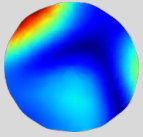
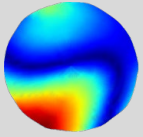
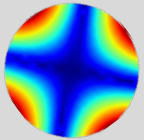
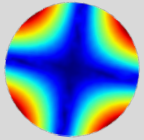
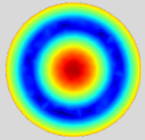
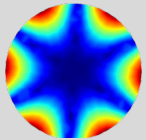
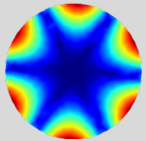
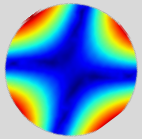
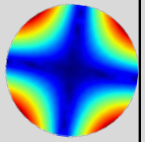
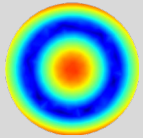
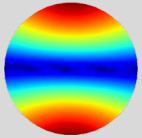
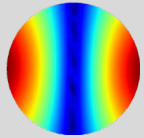
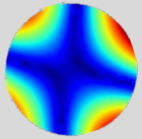
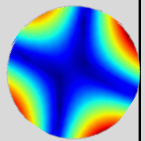
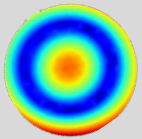
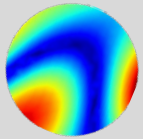
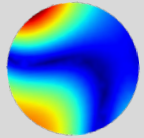


Picture of
IDOX sample



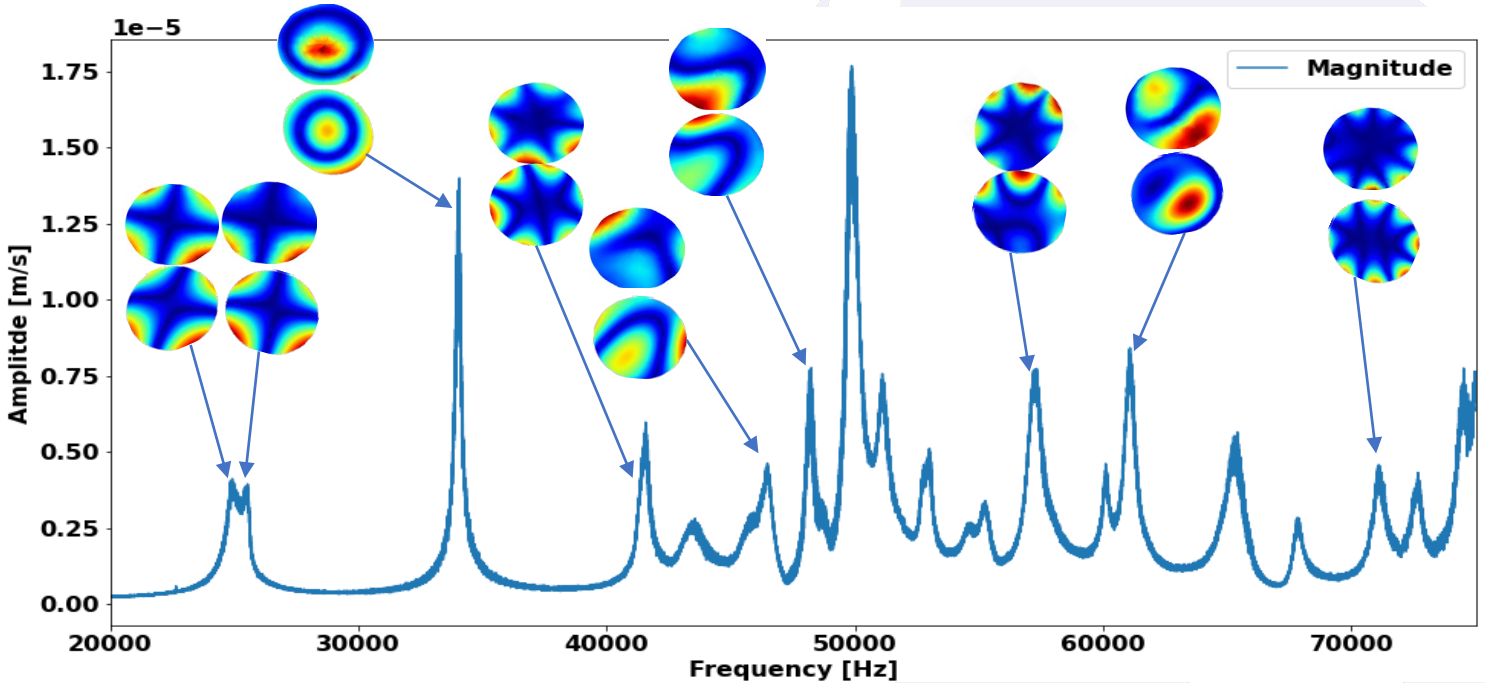
Comparison of Material Type Inversion

- Higher error than typical
- Importance of mode matching
- Importance of material selection

Data	Material Type	Mode 1	Mode 2	Mode 3	Mode 6	Mode 7	Inversion RMS Error
Measured	NA						NA
Simulated	Isotropic						1.69%
Simulated	Transverse Isotropic						3.25%
Simulated	Transverse Isotropic Euler Rotation						1.57%

IDOX Spectra and Mode Matching

- Subset of all modes that can be matched
- Inversion is only knowledgeable of the frequencies and mode index
- Unable to modify index based on mode flipping and index order swapping



Results

Constant

Free

Isotropic Elastic Constants

- C_{11} = 2.35 GPa
- C_{44} = 1.03 Gpa
- Density = 1807 kg/m^3
- Total Error = 1.69%

	Calculated	Measured	Error %
mode 1	25,154.58	24,920.0	0.94
mode 2	25,157.21	25,540.0	-1.5
mode 3	33,941.81	34,070.0	-0.38
mode 6	46,653.52	46,480.0	0.37
mode 7	46,658.95	48,250.0	-3.3

Transverse Isotropic Elastic Constants

- C_{11} = 3.11 GPa
- C_{44} = .98 GPa
- C_{33} = 8.63 GPa
- C_{66} = 5.82 GPa
- C_{13} = 2.58 GPa
- Density = 1807 kg/m^3
- Total Error = 3.25%

	Calculated	Measured	Error %
mode 1	25,796.78	24,920.0	3.52
mode 2	25,818.24	25,540.0	1.09
mode 3	35,961.25	34,070.0	5.55
mode 6	47,739.94	46,480.0	2.71
mode 7	47,745.72	48,250.0	-1.05

Transverse Isotropic with Euler Rotation Elastic Constants

- C_{11} = 3.23 GPa
- C_{44} = .96 GPa
- C_{33} = 8.15 GPa
- C_{66} = 5.81 GPa
- C_{13} = 2.98 Gpa
- Z-X-Z Rotation
  (22.51° - 12.56° - 53.68°)
- Density = 1807 kg/m^3
- Total Error = 1.57%

	Calculated	Measured	Error %
mode 1	25,386.84	24,920.0	1.87
mode 2	25,775.46	25,540.0	0.92
mode 3	34,628.3	34,070.0	1.64
mode 6	46,355.92	46,480.0	-0.27
mode 7	47,154.35	48,250.0	-2.27

Conclusion Future Work

- Mode matching is crucial to correctly identifying materials
- Euler angle rotations needed for complex material

Future work:

- Alternative characterization of material
- More samples
- Better characterization
- Mode Image Inversion

Questions